Studies of Magnetic Materials

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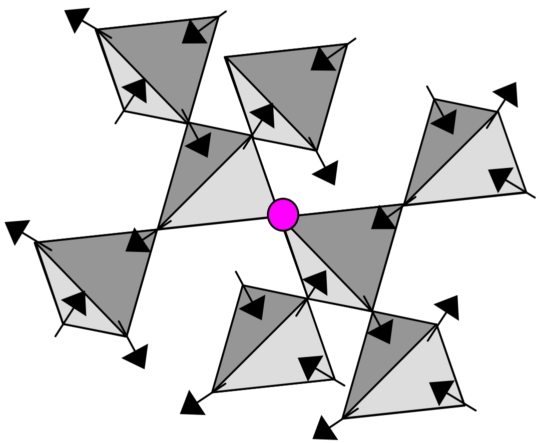
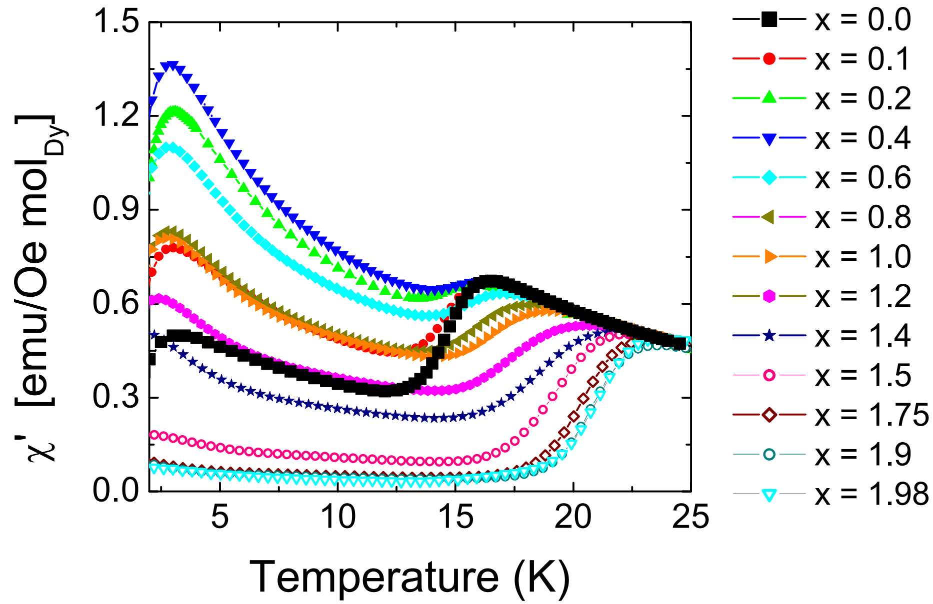


Diluted Spin Ice



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We are conducting an ongoing study of the collective behavior of geometrically frustrated magnetic materials, which provide model systems for the dynamics of large frustrated networks. We have recently studied the “spin ice” compound, dysprosium titanate, in which the low temperature statistical mechanics of the spins are exactly analogous to that of the protons in frozen water. One consequence of the unusual dynamics of this spin system is that the spin freezing is first suppressed and then enhanced by the addition of increasing amounts of disorder (in the form of non-magnetic ion substitution). This can be seen in the accompanying plot of a.c. magnetic susceptibility for different dilutions where the drop indicates the onset of spin freezing.

The NSF supports our research group primarily to study the properties of magnetic materials. Magnetic materials are an essential component of many important industries, such as the multi-billion dollar data storage industry. Future advances in our understanding of these materials will only increase their industrial importance. For example, a class of materials known as ferromagnetic semiconductors, which we study with NSF support, may lead to a new paradigm for designing and building integrated circuits. Magnetic materials are also very important in the study of basic physics, since they display unusual phenomena that are not seen in any other class of materials. An example of this is given by a class of materials known as geometrically frustrated magnets, which we study with NSF support. Geometrically frustrated magnets, in contrast to ordinary magnets, cannot attain a unique lowest-energy arrangement for the magnetic properties of their constituent atoms. The key to achieving this surprising “frustrated” magnetic state is to arrange the magnetic atoms at the corners of connected triangles. These systems are fundamentally different from other magnetic materials, and their properties at low temperatures cannot be understood within current theoretical models. Understanding geometrical frustration in magnets has the potential for providing insight into systems that may form the foundation for novel future computational techniques.

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Peter Schiffer's group has an active research program into the properties of granular materials, i.e. materials which are composed of collections of separated solid grains. Such granular media (e.g. sand) display a variety of complex dynamic and static properties which distinguish them from materials in bulk solid or liquid phases. Such materials are important to processes across a wide range of industries from agriculture to mining to pharmaceuticals. Current research projects involving undergraduates supported by the Penn State MRSEC include studies of local jamming induced by a solid object being pushed through the grains, and the effects of boundaries on such processes. One recent finding is that the penetration force required to push an object toward a solid boundary through the grains feels the boundary with a characteristic and well-defined length scale, and the penetration force actually decreases upon approaching a smooth boundary (Nature **427**, 503 (2004)).